

Rover Systems

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1. System Description

a. Mobility.

1. Ground contact is through off-the-shelf inflatable rubber off-road tires of approximately 28inch diameter. The suspension is 4-wheel independent, with all-wheel drive, and tires that are large relative to the chassis size.



Figure 1 - Front of vehicle is at right side of photograph.

2. Vehicle locomotion is accomplished through standard suspension wheeled-vehicle technology. The vehicle has 4-wheel steering, with all 4 wheels having similar A-arm and steering linkage mechanisms. Braking is accomplished by two disc brakes--one for the front axle and one for the rear axle--on the main drive train power shaft. Each brake is

mounted on the drive shaft just before the axle differential.

3. Vehicle actuation methods are as follows:
 - a. Steering - Ultramotion 2-B.125-DC426_12-4-P-/4-300 linear actuator for each axle.
 - b. Brake - Cirrus 650 servo mechanically actuating a hydraulic brake master cylinder for both front and rear.
 - c. Gear Shift - Cirrus 650 servo for switching between forward and reverse.
 - e. Throttle - Airtronics 94102 servo directly coupled to carburetor butterfly valve.

b. Power.

1. Vehicle power is from a 22hp 2-stroke 244cc internal combustion engine, with an integrated continuously variable automatic transmission. The vehicle also has a 12 volt 18Amp-hour sealed AGM battery (Power Sonic PS-12180) for storing and supplying electricity to the various components of the vehicle. Electricity is generated using a Honda Civic alternator.
2. The vehicle consumes a maximum of approximately 900watts peak power.
3. The engine is powered by standard 2-cycle 92 octane gas-oil mixture.

c. Processing.

1. The vehicle uses an off-the-shelf 2.6 GHz Pentium 4 processor for the main controller. This main controller forms the 'brains' of the vehicle, and all planning and higher level control is handled with this controller. The main controller interfaces with the vehicle's front-mounted distance sensor and the DGPS sensor.

There are also 2 real-time 25 MHz HC12 microcontrollers that interface with and process external signals and control components which together form the real-time system. The first microcontroller controls the brake motor, throttle motor, steering motor, engine-gear motor, engine running sensor, and transmission velocity signal. The second microcontroller interfaces to the accelerometers, distance sensors (sides and rear), operating lights, operating audible alarm, limit switches, and pause signal.

2. The overall architecture is a 'goal' based system, implemented with a 'stack' data structure at its core. The initial challenge course waypoints are loaded onto the stack. This stack is very dynamic, in that each major goal is subsequently divided into a series of smaller goals, and as new obstacles are detected and avoided, the localized/short-term goals are removed or modified as needed.

Macro Route planning is accomplished through a search of the local obstacle map. The search functions cost metrics include obstacle intensity, distance from straight-line solution, proximity to boundaries, goal direction, and distance traveled. The macro-route is computed for the next waypoint by generating local waypoints at intervals no greater than about 30ft.

The system does not attempt to classify objects in a formal sense, such as 'tree' or 'wall' etc., but instead the system maintains a dynamic localized map of the estimated certainty of the 'impassibility' of obstacles around the present vehicle location based on a weighted metric calculated from the on-board distance sensors. An important aspect of the macro route planner is its ability to do re-planning as needed, due to local obstacles or other vehicles, etc.

When traveling, the main controller calculates an estimated optimal heading and desired velocity for the vehicle for each cycle of the control loop, which depends on the speed, current heading, the localized map of 'impassibility', and is weighted by it's deviation from the straight line path. Desired vehicle velocity is calculated based on the irregularity of the terrain and the vehicle turning angle.

d. Internal Databases.

1. No map data will be stored on the vehicle.

e. Environment Sensing.

1. Vehicle Sensors for sensing the external terrain.
 - a. Forward radar distance sensor - Active Sensing - SICK Laser Measurement System (LMS) 291-S05 to 50 meters.
 - b. Short-range right-side ultrasonic distance sensor - Active Sensing- Horizon is approximately +/-9deg to 2 meters.
 - c. Short-range left-side ultrasonic distance sensor - Active Sensing- Horizon is approximately +/-9deg to 2 meters.
 - d. Short-range rear ultrasonic distance sensor - Active Sensing- Horizon is approximately +/-9deg to 2 meters.
2. Sensors are located as shown in Figure 2 below. The forward laser distance sensor is labeled 'A'. The 3 short range ultrasonic distance sensors are labeled 'B'. In order to simplify the system complexity and increase its robustness, the sensors are mounted rigidly, so there is no actuation or directional control of the sensors. There are no masks, arms or tethers that would otherwise significantly protrude from the vehicle.

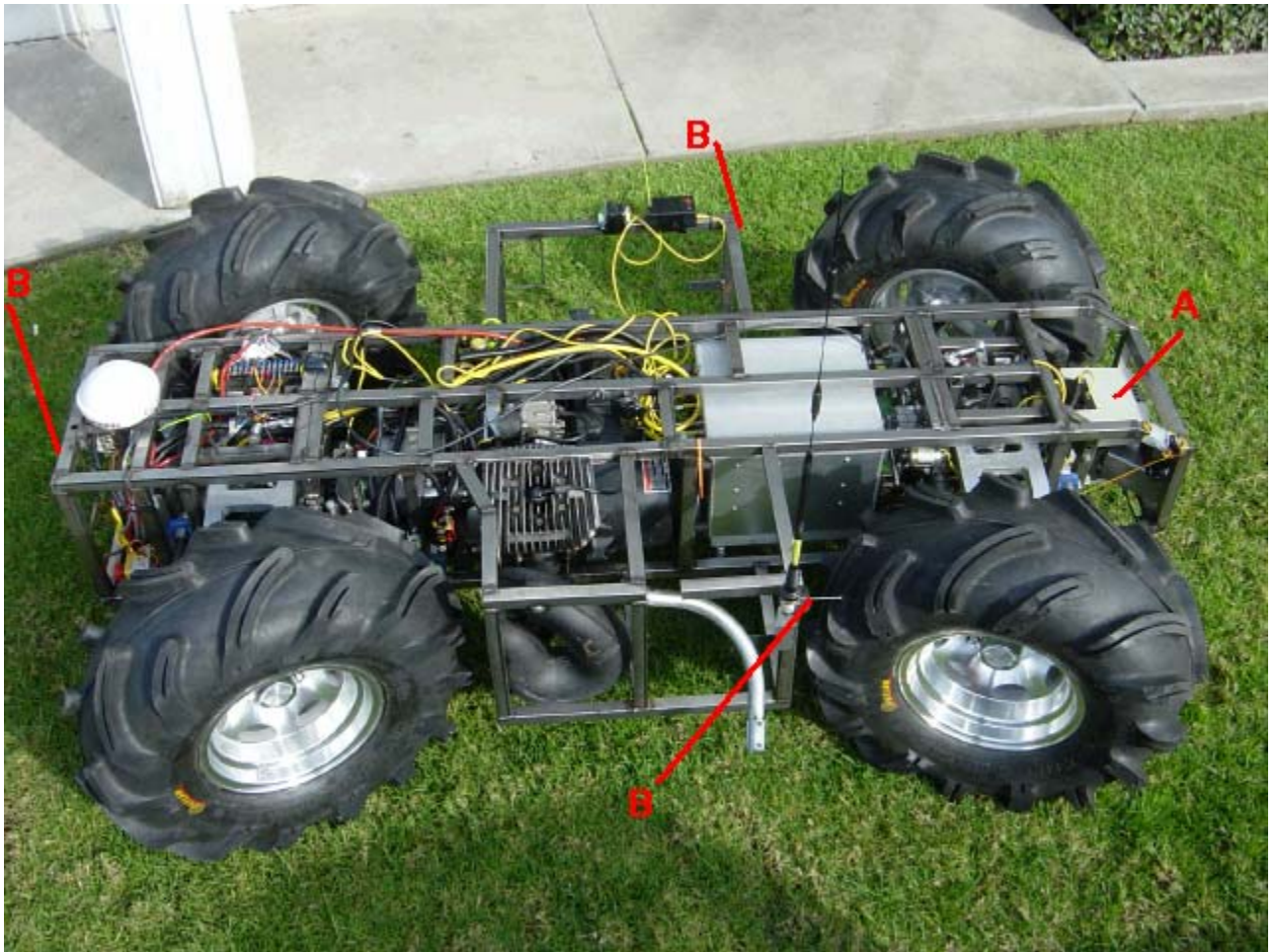


Figure 2 - Distance Sensor Locations

f. State Sensing.

1. The sensors the vehicle uses for sensing vehicle state are listed below.
 - a. Trimble AgGPS 114 utilizing Omnistar subscription service for differential signal correction.
 - b. Wireless Disable and Pause (Digital from DARPA-supplied box)
 - c. Wheel Angle for Front and Rear (linear potentiometer)
 - d. Accelerometer Forward/Vertical (Dual axis) - Analog Devices ADXL311 $\pm 2g$ Dual-Axis Accelerometer.
 - e. Accelerometer Tilt (Dual axis) - Analog Devices ADXL311 $\pm 2g$ Dual-Axis Accelerometer.
 - f. Speedometer (Inductive) - Omron E2E-CR8BI
 - i. Engine Speed (Inductive) - Omron E2E-CR8BI
2. The vehicle state sensors are routed directly to the microcontrollers, which process and format the data for access by the main controller. The microcontrollers are used for closing the loop of the servo-controlled axes, to achieve the commanded position from the main

controller. The accelerometers provide information about the localized terrain including tilt, ascent/descent angle, and terrain roughness, which limit vehicle ground speed, turning radius, and acceleration/deceleration. The main controller software implements a 'chassis' object which performs higher level control and access to the vehicle state sensors through the microcontrollers.

g. Localization.

1. The sole method of geolocation is through an off-the-shelf 5 Hz WAAS-capable Trimble AgGPS 114 utilizing Omnistar subscription service for differential signal correction.
2. The vehicle handles GPS outages through a basic inertial and ground contact based velocity estimation algorithm. The vehicle receives acceleration data from the accelerometers (from which actual velocity is estimated), and speedometer and the wheel angle are continuously combined to provide an estimated position (after integration) of the vehicle. A GPS outage will cause the accuracy of the estimated vehicle position to be progressively degraded until the GPS signal is reestablished.
3. During each cycle of the vehicle control loop, the current estimated location is compared against the boundaries of the current Route waypoint. If the vehicle is found to be (possibly) outside (due to GPS inaccuracies or an incorrect turn, etc.), the vehicle temporarily alters its primary goal (normally, of following it's planned route to get to the next waypoint) and attempts to return to within the boundary as soon as possible. The path planning algorithms cannot search for paths outside of route boundaries.

h. Communications.

1. There are no signals broadcast from the Challenge Vehicle during the challenge or QID.
2. The only wireless signals the Challenge Vehicle receives are the DGPS signals for the off-the-shelf DGPS receiver and the signals received by the DARPA-supplied E-Stop and Tracking boxes.

i. Autonomous Servicing

1. The vehicle will not refuel during the race.
2. There are no planned servicing activities that will be performed on the vehicle at the checkpoint.

j. Non-autonomous control.

1. The vehicle utilizes a Wireless Ethernet Bridge plugged into an RJ-45 connector on the side of the computer box as shown below. The remote control is plugged into connector #18 on the computer box when in use. Both can be easily unplugged for the DARPA competitive events.

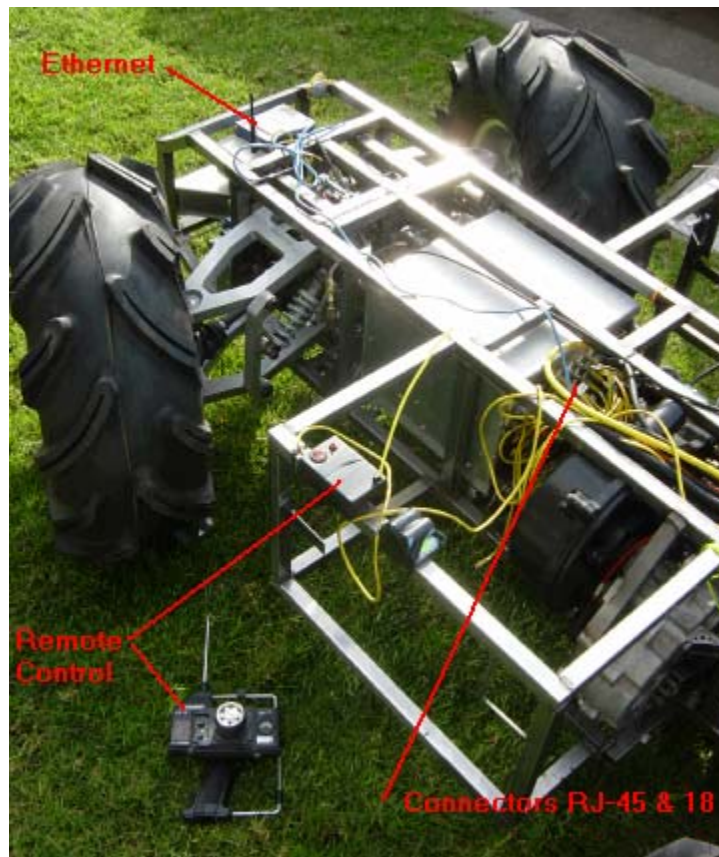


Figure 3 - Remote Control

2. System Performance

a. Previous Tests.

1. The tests performed to date:
 - a. GPS reception and tracking test. The results show that the Trimble AgGPS 114 maintains good reception and localization with its mounting point at the back of the vehicle, even when reception is partially obstructed.
 - b. Engine speed control.
 - c. Preliminary obstacle avoidance check. The path planner accurately picks routes around the shown obstacles.
 - d. Simulated desert environment testing of the control box.
 - e. Remote control of vehicle.

b. Planned Tests.

1. Planned tests that will be conducted in the process of preparing for the Challenge:
 - a. Reactive obstacle avoidance test - Determine optimal obstacle avoidance controller parameters
 - b. Dynamic route planning and correction test
 - c. Sensor performance and limitation when traveling over highly

irregular terrain test

3. Safety and Environmental Impact

- a. The top speed of the vehicle is 40 mph, implemented as a software-controlled limit.
- b. The maximum range of the vehicle is 250 miles over moderately irregular terrain without refueling.

c. Safety Equipment

- 1. Vehicle fuel is stored in two tanks holding 7 gallons and 13 gallons, for a total of 20 gallons. Each tank has a pressure release valve.
- 2. Due to the small size and limited carrying capacity of the vehicle, there is no on-board fire suppression system.
- 3. Audio and visual warning devices:
 - a. Operating Audible Alarm - two ECCO 510 rated for 97 db at 4 ft
 - b. Operating Lights - 4 (1 per side) Maxxima M40200Y Amber LED Transportation Turn Lights (5.25"W x 3.375"H)
 - c. Brake Lights - 2 (both at rear) Maxxima M40200R Red LED Transportation Stop Lights (5.25"W x 3.375"H)

d. E-Stops.

- 1. There are two Wireless E-Stop signals returned from the DARPA supplied box. These operate as follows:
 - a. When the 'pause' signal is received for the DARPA supplied box, the signal is received by microcontroller 2, which immediately notifies the host computer, which then quickly brings the vehicle to a controlled stop. The engine will remain on and the brakes will stay applied to keep the vehicle from moving. When the 'pause' signal is removed, microcontroller 2 will wait 5 seconds, then signal the host computer to allow movement of the vehicle.
 - b. The vehicle uses the 'disable' relay provided by the DARPA supplied box. When the 'disable' signal is received this relay removes power from the engine and computer box, which automatically engages the fail-safe Emergency Brake. As long as the 'disable' E-Stop is activated, nothing on the vehicle can operate. When the 'disable' E-Stop signal is manually cleared, power is applied to the main computer box, which proceeds to boot it's operating system. The 'pause' signal should be engaged before manually clearing the 'disable' E-Stop signal.
- 2. The Manual E-Stop switch is a NEMA 4X Enclosure-mounted, CSA certified, 10A, pull-to-reset switch with a red mushroom button. The switch is located as shown in Figure 4 below. The Manual E-Stop is wired in series with the DARPA 'disable' relay, so that power to both the engine and the computer box is removed when the Manual E-Stop is depressed.

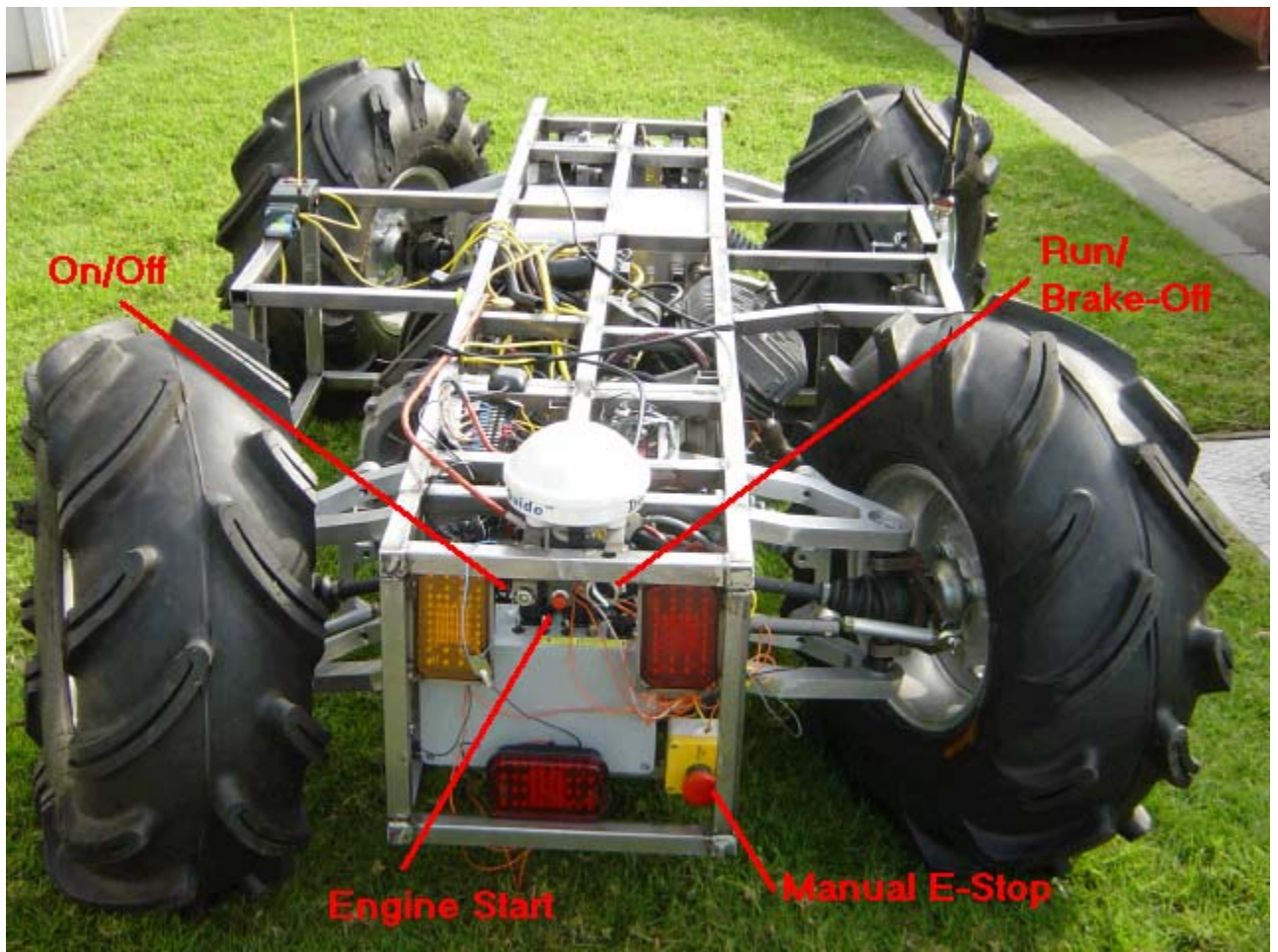


Figure 4 - E-Stop location on Vehicle

3. The vehicle can be towed using a conventional tow truck, but the preferred method of transporting it is using a truck bed, such as flatbed or pickup due to the small size and low weight of the vehicle. The vehicle uses an automatic transmission which returns to neutral when the engine is off. The Run/Brake-Off switch should be switched counter-clockwise to the Brake-Off location to disengage the fail-safe brake.

e. Radiators.

1. The only item that actively radiates EM energy is the forward laser distance sensor, with a maximum output of 10mW.
2. The items that could be an eye or ear safety hazard are:
 - a. Operating audible alarm - OSHA compliant to standard 1910.95.
 - b. Forward laser distance sensor - OSHA compliant to standard 1910.97.
 - c. Left ultrasonic distance sensor - OSHA compliant to standard 1910.95.

- d. Right ultrasonic distance sensor - OSHA compliant to standard 1910.95.
 - e. Rear ultrasonic distance sensor - OSHA compliant to standard 1910.95.
3. There are no significant safety hazards with the exception of the DARPA supplied RF 2.6GHz antenna. Personnel should stay more than 23cm from this antenna when the vehicle is operational.

f. Environmental Impact.

- 1. Due to the smaller size of this vehicle and its standard steerable wheeled design, it will not cause environmental damage nor will it mark or harm roadways.
- 2. The maximum physical dimensions of the vehicle are 84" long, 50" wide, and 28" high (See Figure 1). The fueled weight is approximately 670lbs.
- 3. The total footprint area of the vehicle is approximately 170in², and using the fueled weight above, this gives a calculated maximum static ground pressure of about 4.0psi.